TECHNOLOGY ASSESSMENT AND SCREENING ANALYSIS

APPENDIX B SUPPLEMENT

TO THE WATER HEATER RULEMAKING FRAMEWORK

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PACIFIC NORTHWEST NATIONAL LABORATORY
Richland, Washington 99352

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TECHNOLOGY ASSESSMENT AND SCREENING ANALYSIS APPENDIX B SUPPLEMENT TO THE WATER HEATER RULEMAKING FRAMEWORK

EXECUTIVE SUMMARY

This report discusses various design options for improving the energy efficiency of gas-fired, oil-fired, and electric storage-type water heaters, and addresses Section 2.3 of the Water Heater Rulemaking Framework document (dated June 11, 1997) that was distributed at the Water Heater Standards Rulemaking Workshop held in Washington, D.C., on June 24, 1997. Following discussions at the workshop, the design options have been screened and pared down to a list of options that will be used by the U.S. Department of Energy (DOE) for the engineering and economic analysis.

Since the workshop, DOE has received 15 comments from stakeholders pertaining directly to the design options discussed here. A number of the comments supported the design options listed below. DOE invites stakeholders to review and provide additional comments on these design options, particularly if they include specific references or reports that may reveal information not considered here.

Design Options to be Used in the Engineering Analysis

Design Options - Description	Gas	Electric	Oil
Heat Traps	X	X	X
Plastic Tank	X(1)	X	
Increased Jacket Insulation	X	X	X
Insulating the Tank Bottom (Electric Only)		X	
Improved Flue Baffle/Forced Draft	X		X
Increased Heat Exchanger Surface Area	X		X
Flue Damper (Electromechanical)	X		
Side-Arm Heater	X		
Electronic (or Interrupted) Ignition	X		X
Air-Atomized Burner (Oil-Fired Only)			X
(1) used in conjunction with the side-arm heater option			

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INTRODUCTION

On March 4, 1994, the U.S. Department of Energy (DOE) proposed standards for eight products including water heaters (59 FR 10464). On January 31, 1995, DOE published a rulemaking determination indicating that it had decided to proceed with a separate rulemaking for three of the eight products. For these three products, one of which is water heaters, DOE would be publishing a revised Notice of Proposed Rulemaking (NOPR) (60 FR 5880).

DOE has received comments on a wide range of issues regarding the proposed standard for electric water heaters, including DOE's estimates of average household hot water use, the costs of heat pump water heaters, and the extent to which the proposed standard would result in fuel switching. In addition, the comments addressed the impacts of standards on consumers, including low income households, households with small electric water heaters installed in confined spaces, and those with large water heaters that take advantage of reduced off-peak electric utility rates. DOE agrees that these issues need to be reassessed. Because fully addressing these issues may require substantial changes in the analysis of the impacts of water heater standards, DOE will issue a new proposed rule.

Building on past analysis and incorporating public comments to the 1994 NOPR, a draft screening analysis was prepared and presented at the Water Heater Standards Rulemaking Workshop held in Washington, D.C., on June 24, 1997, for review and comment from stakeholders. Section 4 of the Interpretive Rule articulates factors that DOE will take into account in screening design options, selecting candidate standard levels, and selecting proposed and final standard levels. The process requires that this screening of design options be one of many opportunities to gather and consider input on whether a design option is technologically feasible; is practicable to manufacture, install and service; has significant adverse impact on utility of the product to consumers; or adversely affects health or safety. With this document, DOE is identifying the screened design options it will consider for further analysis. DOE invites stakeholders to review and provide additional comments on these design options, particularly if they include specific references or reports that may reveal information not considered here.

This report discusses various design options for improving the energy efficiency of gas-fired, oil-fired, and electric storage-type water heaters, and addresses Section 2.3 of the Water Heater Rulemaking Framework document (dated June 11, 1997) that was distributed at the workshop. Following discussions at the workshop, the design options have been screened and pared down to a list of options that will be used by DOE for the engineering and economic analysis.

Status Update on the Issue of "Gas-Fired Water Heater Ignition of Flammable Vapors"

The issue of flammable vapor ignition was brought up at the workshop. The Consumer Product Safety Commission (CPSC) has been working closely with industry toward developing a voluntary standard to address the issue of "gas-fired water heater ignition of flammable vapors." The goal of developing a performance test methodology (standard) is to have uniform criteria against which a water heater's resistance to flammable vapor ignition can be evaluated. A second objective is to design a water heater that is resistant to flammable vapor ignition when tested in accordance with the test method. The Gas Appliance Manufacturers Association (GAMA) has been coordinating this effort on behalf of industry. Based on a 30-month estimate for a proposed test method to be reviewed and revised, CPSC staff expect the revised test method (standard) incorporating vapor ignition protection to be sent to the American National Standards Institute (ANSI) in 1999 for approval as a national standard. DOE has asked CPSC for a detailed time schedule, but the industry consortium has said that the information is confidential. Nevertheless, in developing the energy efficiency standards for residential water heaters, DOE will consider the activities and status of the development of a CPSC-industry voluntary standard for gas water heaters.

Stakeholder Comments

Since the workshop, DOE has received several written comments (refer to DOE Docket Number EE-RM-97-900, Water Heater Standards Rulemaking, located in DOE's Freedom of Information Reading Room) from stakeholders pertaining directly to the design options discussed. A total of 15 comments were received from manufacturers, associations, gas and electric utilities, a consumer group, and a consumer. DOE has considered all the comments it received and presents those comments that specifically discuss DOE's screening of design options. Section 4 of the Interpretive Rule establishes the process for developing efficiency standards. This process is designed to provide for greater and more productive interaction between DOE and stakeholders throughout the process. It is also designed so that key analysis is performed earlier in the process, with early opportunities for public input to and comment on that analysis. The process is consistent with the procedural requirements of law, but adds some important steps to enhance the process.

Laclede Gas Company and the American Gas Association (AGA) advised DOE to follow statutory requirements and not to screen out any design options [Laclede, No. 9 at 12 and AGA, No. 10 at 1,10]. Section 4 of the Interpretive Rule articulates factors DOE will take into account in screening design options, selecting candidate standard levels for further analysis, and in selecting proposed and final standard levels. The Energy Policy and Conservation Act (Act), as amended, directs DOE to determine if a standard is economically justified based on the seven factors found in section 325(o). The screening process is just one part of this process. Therefore, DOE is following the criteria listed in the Act and the Interpretive Rule and will proceed to reject certain design options from the analysis based on this consideration. In reference to Section 4(a) of the Interpretive Rule, GAMA provided a list of design options to keep and a list to screen out and included reasons for screening them out [GAMA, No. 5 at 5-7]. Bradford White Corporation supported the GAMA design options discussed at the workshop [Bradford White, No. 6 at 3]. Edison Electric Institute (EEI), Southern Company, and Virginia Power supported DOE's screening analysis and list found in Appendix B, Supplement to the Water Heater Rulemaking Framework, June 11, 1997 [EEI, No. 7 at 3, Southern Company, No. 12 at 1-2, Virginia Power, No. 14 at 2].

DISCUSSION OF DESIGN OPTIONS

The design options considered here are grouped in two categories. The first category is the design options that will be used by DOE in the engineering and economic analysis. The second category contains the design options that have been eliminated from further consideration. The discussion under this second category also includes the screening criteria that have been used by DOE.

Design Options to be Used in the Engineering Analysis

The first eight design options listed below are being considered for engineering and economic analysis because they are currently being applied to commercial or residential water heaters and pass all of the screening criteria. In the engineering analysis phase, certain of these design options will be combined to meet an efficiency level based on the lowest life cycle cost estimate. To save time and resources, the entire analysis may not be completed for other design options which provide similar efficiency levels. The last design option is being considered because prototype units are available and field tests are being planned in the near future.

- Heat Traps
- Plastic Tank
- Increased Jacket Insulation
- Insulating the Tank Bottom (Electric Only)
- Improved Flue Baffle/Forced Draft
- Increased Heat Exchanger Surface Area
- Flue Damper (Electromechanical)
- Side-Arm Heater
- Electronic (or Interrupted) Ignition
- Air-Atomized Burner (Oil-Fired Only).

Heat Traps

The heat conducted and convected through the fittings (water pipes, drain valve, pressure relief valve, and thermostat) accounts for about 15% of the total standby loss in a typical residential-size gas-fired water heater (Paul et al. 1993). A heat trap is a device or arrangement of piping that keeps the buoyant hot water from circulating through a piping distribution system because of natural convection. When there is no draw of hot water, this device prevents water in the hot water outlet line from getting back into the tank as it cools off; and prevents hot water in the tank from circulating back into the cold water inlet line. Thus, by containing the hot water in the storage tank, the heat trap minimizes standby loss. These devices can be integral to the tank design or independently attached to the inlet and outlet pipes during installation at the site. Paul et al. (1993) have shown that heat traps can increase the energy factor (EF) of residential-size water heaters by 1%. Also, the effectiveness of a heat trap can be increased by insulating its exposed portion.

Conventional heat traps are currently made in two styles. In the first style, a floating plastic ball blocks the cold water inlet. The buoyancy of the plastic holds it in place until water is drawn. The force of water is strong enough to push the ball out of the way as water enters the tank. The second style is used for the hot water outlet. In this heat trap, the ball is denser than water, and the weight of the ball seals the outlet until hot water is drawn and the water pressure lifts it out of the way (DOE 1993). A small bypass channel is left for water to escape back into the inlet line from the tank as it expands after a large draw fills the tank with cold water.

Other heat trap designs have also been invented and produced. These include U-shaped pipes (Nisson 1994), flexible seals (Harvey 1994), flaps, springs, and other mechanisms.

Bradford White Corporation concludes that heat traps are not a design option because they are noisy and viewed as a deterrent for product utility by consumers and cost more than the energy savings can repay [Bradford White, No. 6 at 1]. On the other hand, GAMA recommends that heat traps be considered in the DOE analysis because this technology is already implemented in most models [Workshop Transcript, No. 1J at 163].

DOE agrees with GAMA's comment and will consider this design option in the engineering analysis.

Plastic Tank

Plastic water heater tanks can be constructed using a seamless, blow-molded polybutylene inner tank with a filament-wound fiberglass outer tank, similar to the fabrication of tanks for water softeners (Rheem Mfg. Co. 1993). The lower heat conductivity of plastic compared to metal reduces the amount of heat conducted through the tank wall to the insulation and to the feed-throughs. However, the plastic tank cannot be used with standard center-flue gas-fired water heaters or with oil-fired water heaters, because the plastic cannot withstand the high temperatures produced by the flames. This option can be used only with electric water heaters or with indirect water heating techniques (e.g., the side-arm water heater or heat pipe technologies) that avoid flame temperature problems.

GAMA recommends eliminating plastic tank water heaters because it is not an efficiency improving design option. GAMA believes DOE should rely on increased insulation thickness for efficiency improvements [GAMA, No. 5 at 6].

DOE believes that the plastic tank construction method enables an improved process of insulating the tank bottom. Therefore, this design option may, in fact, reduce standby losses in certain applications and should be investigated further. DOE will consider this design option for the engineering analysis.

Increased Jacket Insulation

The jacket (sides and top) of the water heater is insulated with polyurethane foam insulation or fiberglass insulation. Because polyurethane foam has a lower thermal conductivity than fiberglass, it is more widely used. Most water heaters on the market today have at least 1-inch thick foam insulation, while some manufacturers provide 2- or 3-inch thick insulation, as well. The bottom of the tank (below the burner assembly) of a gas-fired water heater is seldom insulated and is the source of significant heat loss.

It is reported that for a gas-fired water heater with a 40-gallon storage tank with 1-inch polyurethane foam insulation around the jacket and fiberglass insulation around the combustion chamber, the jacket losses are about 50% of the total standby losses (Paul et al. 1993). For a tank with more than 40-gallons storage volume, the jacket losses as a percent of the total standby losses will be even higher. Although increasing the insulation thickness reduces the standby loss, the increase in the overall diameter of the water heater may pose some installation problems. There will also be an increase in shipping costs because fewer heaters will fit in a truck.

Bradford White Corporation commented that the uncertainty over the blowing agent for foam insulation be handled by limiting the cavity size [Bradford White, No. 6 at 2]. DOE will be in contact with the Environmental Protection Agency, manufacturers of blowing agents, and water heater manufacturers to assess any adverse impacts that could result from this uncertainty about blowing agents. DOE will include this design option in the engineering and economic analysis.

Insulating the Tank Bottom (Electric Only)

The bottom of the tank of an electric water heater will be insulated with foam insulation as an alternative design option to reduce the standby heat loss. This is not conventionally done, however, DOE intends to consider this as an added energy saving measure. NIST plans to test some sample units to quantify the energy savings or the increase in energy factor by using this design option. DOE will include this design option in the engineering and economic analysis.

Improved Flue Baffle/Forced Draft

The standard flue baffle is a twisted strip of metal inserted into the flue that increases the turbulence of flue gases and improves heat transfer to the walls of the flue. The geometry of the flue baffle can be modified to increase its effectiveness. One manufacturer uses a flue with many small rectangular fins attached on its inside surface. The arrangement and size of the fins in various models increases the recovery efficiency of the water heater. Other baffle configurations that increase recovery efficiency are also available.

A research project funded by the Gas Research Institute (GRI) reviewed technical literature, manufacturers' literature, and patents to determine what new technologies are applicable to heat exchangers that involve flue gases from combustion of natural gas (Bergles et al. 1991). The conclusion was that significant increases in the convective heat transfer coefficient could be achieved with the use of heat transfer enhancement devices. The study suggested that in some cases, an increase in heat transfer coefficient might be accompanied by an increase in the pressure drop (due to an increase in the friction factor). The study identified twisted-tape inserts as a potential heat transfer enhancement device for water heaters.

Burners in fuel-fired water heaters are placed below the storage tank, with the flue extending up through the center of the tank through a draft hood. The combustion products enter the flue tube at a very high temperature (approximately 2300°F) and transfer heat by convection and radiation to the tube wall, and then by conduction to the water. When a baffle, such as a flat plate, is inserted in the flue, increased heat transfer occurs from the hot combustion products to the flue wall. The increase in the heat transfer is even greater when a twisted baffle tape is inserted in the flueway of a water heater. The twisted tape augments the convective heat transfer from the flue gases to the wall surfaces. In addition, the hot tape transfers heat to the water-tube walls by radiation.

Beckermann and Goldschmidt (1986) investigated experimentally and empirically the effects of velocity of the flue gases, the twist (i.e., number of turns) of the tape, and the surface emissivities on the total heat transfer (convection and radiation) in a fuel-fired water heater. They reported that compared to an empty tube, the flue tube with twisted tape enhances the overall heat transfer performance by as much as 50%.

This design option of an improved flue baffle can increase the recovery efficiency to about 80-85%, depending on the specific geometry. At the upper end of the recovery efficiency range, the water heater would require power venting or induced draft and corrosion resistant flues for safe operation. Since the DOE believes that condensing gas fired water heaters are not applicable in all building situations, it will not consider recovery efficiencies above 80% in its analysis.

In addition to an increase in efficiency, there is also a reduction in standby loss. The off-cycle standby loss is reduced by the additional restrictions to airflow due to the increased baffling.

Because enhanced or increased flue baffling increases pressure drop across the flue, the combustion products may have to be forced through the flue with a fan or blower. Venting combustion products through a horizontal venting system also requires a fan or blower. When the blower forces fresh air into the chamber, the configuration is called a forced draft system. By contrast, when the blower is located in the flue-gas exit the configuration is called an induced draft system. In an induced draft system the blower is exposed to hot and potentially corrosive flue gases and, therefore, should be made of materials that can withstand these conditions.

Several manufacturers currently make water heaters with induced-draft blowers. However, this feature is usually added to allow sidewall venting and may not be accompanied by any increase in flue baffling.

Using a fan to force the flue gases through the baffle with either an induced-draft blower (downstream of the water heater) or a forced-draft blower (upstream of the water heater), can increase the recovery efficiency and reduce the off-cycle flue losses. The increased recovery efficiency resulting from this design option may necessitate relining or otherwise modifying the vent systems to prevent corrosion or damage from condensation.

Some manufacturers make water heaters with induced draft fans that, in addition to pulling the combustion products through the water heater, also draw excess air into the flue gases prior to venting. The additional air cools the flue gases leaving the water heater to a low enough temperature so that standard plastic piping can be used for venting. This eliminates any problems with corrosion. Plastic piping is often cheaper and easier to install than sheet metal or masonry chimneys.

While this technique of flue gas dilution does not necessarily increase water heater efficiency by itself, when combined with an improved flue baffle that increases recovery efficiency, it can help avoid venting problems. DOE will include the improved flue baffle/forced draft design option in the engineering analysis.

Increased Heat Exchanger Surface Area

There are a number of ways to improve the transfer from the flue gas to the water including the use of increased heat exchanger surface area, improved flue baffle, etc. The improved heat transfer leads to an increase in the thermal efficiency of the water heater. However, the thermal efficiency is limited by the so-called “condensing level” of about 84%, at which condensation of the flue gases begins to occur in the flue or vent pipe that may cause corrosion of the surfaces. To avoid such problems, use of this design option will be limited to an 80% recovery efficiency (or about 82% thermal efficiency) level.

The design option of increased heat exchanger surface area can be achieved using, among others, the following two modifications of the basic design of the standard gas-fired storage water heater. One is to surround the combustion chamber with water and the other is to use a number of smaller flue tubes instead of one large flue to vent the exhaust gases from the combustion process. This design option can increase recovery efficiency sufficiently so that condensation (and hence corrosion) is likely to occur in venting systems that are not lined with double-walled sheet metal.

- Submerged Combustion Chamber. The combustion chamber in a standard gas-fired storage water heater is below the water tank, and the bottom of the tank (below the burners) is seldom insulated. Therefore, the water heater loses heat from the bottom of the tank. The sides and bottom of the combustion chamber are not surrounded by water. By inserting the combustion chamber into the storage tank, more of the combustion energy can be recovered. Standby losses are reduced somewhat because of restrictions on the air flow through the combustion chamber and flue.

- Multiple Flues. The multiple-flue design uses several smaller flues in place of one large central flue in the middle of the storage tank. The increased surface area for heat exchange between the flue gases and the water in the tank yields an increase in recovery efficiency. One manufacturer is currently offering this design in a residential gas-fired water heater.

DOE will consider the use of either of these design modifications as a design option for the engineering analysis.

Flue Damper (Electromechanical)

Gas-fired storage water heaters are equipped with a draft hood connecting the flue pipes to a vent pipe or chimney. During off-cycle, the water heater loses heat by natural convection and conduction through the vent pipe or chimney. A damper can be installed either at the flue exit or in the vent pipe to minimize the off-cycle heat losses. A flue damper is installed upstream of the draft diverter, while the vent damper is installed downstream of the draft diverter.

Electric flue dampers are activated by an external source of electricity. The dampers open when combustion starts and close immediately after combustion stops. Therefore, there is a greater reduction in off-cycle losses compared to buoyancy activated dampers [see Flue Damper (Buoyancy Operated)]. When the damper reaches the open position, an interlock switch energizes the solenoid and enables the gas ignition circuit. Therefore, the burner cannot be ignited when the damper is in the closed position. Because the dampers open and close immediately, no bypass is needed. A knockout is provided to vent the flue gases from a standing pilot. The electric flue damper needs a 24-volt electric source and consumes about 5 W when the gas supply is off.

Flue/vent dampers have no effect on the steady-state performance of the water heater. However, in a field test of a 70-gallon gas-fired storage water heater with rated input capacity of 36,000 Btu/h, the addition of an electric flue damper reduced the standby loss from 113,000 Btu/day to 46,000 Btu/day. The overall system service efficiency increased from 61% to 65%.

Because these devices are currently being sold on commercial water heaters, this design option passes all the screening criteria. It should be noted that in addition to the increased installation cost for electrical supply, maintenance costs are expected to be higher, as well.   DOE will include the design option of the electromechanical flue damper in the engineering analysis.

Side-Arm Heater

The side-arm heater design avoids large flue losses by removing the flue from the center of the tank. Water is withdrawn from the bottom of the tank and heated over a burner in a small, separate heat exchanger. Water is returned to the top of the tank. A small circulation pump moves water through the heat exchanger when the burner is on. The burner could have electronic ignition, which would reduce the pilot light losses. Auxiliary power is supplied by a low-voltage plug-in transformer.

A water heater using this design in combination with electronic ignition and a plastic tank is commercially available. DOE will include this design option in the engineering analysis.

Electronic (or Interrupted) Ignition

The most commonly used ignition system in storage water heaters is a standing pilot ignition (SPI) system. The disadvantage of a SPI system is that it burns gas continuously at a rate of about 400 Btu/h, and only part of this heat is converted to useful energy. In addition to the SPI system, three electronic ignition devices are commonly used in water heating equipment:

- an intermittent pilot ignition device that lights a pilot by generating a spark, which in turn lights the main burner

- an intermittent direct ignition device that lights the main burner directly by generating a spark, and

- a hot surface ignition (HSI) device that lights the main burner directly by generating a hot surface.

Unlike SPI systems that consume gas continuously, these devices operate only at the beginning of each on-period. Although there is no increase in the steady-state efficiency with use of electronic ignition devices, the overall fuel consumption may be reduced. Burner on-time may increase to make up for the heat the standing pilot would have supplied during standby periods.

Electronic ignition devices require an outside source for ignition, usually a 24-volt or a 120-volt system. The power draw of the electrically operated gas valve is between 5 W and 12 W, and power is consumed only when there is a call for heat. Electronic ignition systems also require a control module, which houses the electronic control circuitry and consumes 6 W of power during a call for heat. These systems also need an electronic thermostat that draws 1.2 W of power during the heating period and 0.4 W of power during the standby period. The HSI is a resistive device that draws about 2.5 amps at 120 V (about 300 W of power) for approximately 30 seconds during ignition.

The “interrupted ignition” system for an oil-fired burner activates the spark only until a steady flame is established by using certain controls and sensors. The oil consumption is not affected by interrupted ignition, nor is there an improvement in the recovery efficiency of the water heater. However, this design option not only reduces the igniter’s electricity consumption, but also reduces its maintenance costs because the electrodes do not have to be replaced as often. In addition to changes in controls, the igniter can be made from solid-state electronics, instead of an iron core transformer. This improves performance and also reduces power consumption.

DOE will include the electronic ignition design option in the engineering analysis.

Air-Atomized Burner (Oil-Fired Only)

This is a different type of burner for oil-fired equipment. Instead of relying on pressure to create a spray of fine oil droplets prior to combustion, this burner uses a stream of air to atomize the oil. Compared to conventional burners, this design allows better control of droplet size and mixing with air at lower oil flow rates. Downsizing the burner with the same flue and baffle geometry will give a higher recovery efficiency (Butcher et al. 1997). The combustion process is also cleaner with this burner.

Working water heaters have been made with this design option. There could be a slight improvement from cleaner combustion. Impacts on manufacturability, installation, and service should be minor. Even if the first hour rating were reduced because of the smaller burner, it would still be larger than that of a gas-fired water heater.

GAMA believes that air-atomized burner technology is not yet sufficiently developed to include it as a design option [GAMA, No. 5 at 6]. DOE is including it for further consideration because HeatWise, Inc. (Ridge, New York), a burner manufacturer, is building 100 units of a low-pressure air-atomized burner design for field tests in 1997-98 for a possible market entry in the 1998-99 heating season. DOE will include the air-atomized burner design option in the engineering analysis of oil-fired storage water heaters.

Design Options Eliminated from Further Consideration

This effort by DOE is in accordance with the mandate of the process improvement (Section 4 of the Interpretive Rule, "Process for Developing Efficiency Standards and Factors to be Considered") per the Interpretive Rule (61 FR 36974). In accordance with Section 4(a) of the Interpretive Rule, technologically feasible design options (i.e., those design options that are already in use by industry or options that are proven by research and progressing towards the development of a prototype) have been identified in this report. In addition to technological feasibility, the other screening criteria for the design options are:

- Practicability to manufacture, install, and service
- No adverse impacts on product utility or product availability, and
- No adverse impacts on health and safety.

The following design options have been eliminated from further consideration because they do not meet the screening criteria and other considerations as described in each of their individual discussions. Some of the issues are highlighted by the fact that the design options, if implemented, can be in conflict with national building codes, plumbing codes, or other technical testing criteria. Also, in some cases, they do not meet the criteria of practicability to install and service, or they have adverse impact on product utility or product application, or they are not an efficiency improvement feature.

- Flue Damper (Buoyancy Operated)
- Submerged Combustion
- Directly Fired
- Condensing Option
- Condensing Pulse Combustion
- Advanced Forms of Insulation
- U-Tube Flue
- Thermophotovoltaic and Thermoelectronic Generators
- Reduced Burner Size (Slow Recovery)
- Heat Pump Water Heater Options
- Timer Controlled
- System Application Options
- Sediment Removal Features
- Two-Phase Thermosiphon (TPTS) Design.

Flue Damper (Buoyancy Operated)

This flue damper is a small, very lightweight aluminum dome-shaped poppet that slides up and down in an enclosure placed at the top of the flue of a gas-fired water heater. The buoyancy of the combustion products lifts the poppet, allowing flue gases to enter the venting system. Working prototypes have been built and tested by AGA.

This design option would reduce off-cycle standby losses, but would have no effect on recovery efficiency. This flue damper may not work with high recovery efficiency water heaters because there may not be enough waste heat in the combustion products to provide sufficient buoyancy to lift the poppet.

The standard for gas water heaters (ANSI 1993) requires the burner to shut off if the flue gets blocked for some reason. Thus the effects of a failure of the flue damper to open should be mitigated by the burner controls. More field tests, however, are being planned to address other safety and operational concerns.

GAMA states that the buoyancy operated flue damper is only a concept that needs more research and testing to determine that it will not cause safety problems. A water heater with a buoyancy operated flue damper must also demonstrate compliance with existing appliance safety standards [GAMA, No. 5 at 6].

DOE agrees with GAMA and believes that additional information on safety issues and long-term use is required.

Submerged Combustion

In this design option, the flue products are bubbled through a small volume of water by the pressure from the burner blower. This small amount of water is heated by direct contact with the flue products. The heated water is re-pressurized by a circulating pump and returned to the storage tank.

The direct contact heat exchange process as described above is a more efficient means of transferring heat than in a conventional tube-and-shell heat exchanger, but can also lead to the contamination of the domestic water by the flue products. This can cause health and safety problems for the end users. This design option can also cause conflict with local plumbing codes [e.g., International Association of Plumbing and Mechanical Officials (IAPMO) 1991] with respect to water quality. Local code restrictions for health reasons may also conflict with the atmospheric emissions from the unit. Therefore, DOE is eliminating this design option because of its likely adverse impacts on health and safety.

Directly Fired

In this design option, water is sprayed through a series of baffles above the burner. Flue products are in direct contact with the water, which is re-pressurized by a circulating pump and returned to the storage tank.

The direct contact heat exchange process as described above is a more efficient means of transferring heat than in a conventional tube-and-shell heat exchanger, but can also lead to the contamination of the domestic water by the flue products. This can cause health and safety problems for the end users. This design option can also cause conflict with local plumbing codes (e.g., IAPMO 1991) with respect to water quality. Local code restrictions for health reasons may also conflict with the atmospheric emissions from the unit. Therefore, DOE is eliminating this design option because of its likely adverse impacts on health and safety.

Condensing Option

Condensing the combustion products in the flue gas extracts more heat in the form of latent energy, leading to an increase in the thermal efficiency of the water heater. The flue-gas condensate is corrosive and often contains acids. Therefore, special corrosion resistant heat exchangers and vent linings are required for safe and reliable operation of the water heater. A number of studies and field tests have been conducted to quantify the corrosion characteristics of condensing gas appliances (GRI 1987). Since 1979, Battelle Memorial Institute has been conducting research on corrosion-resistant heat exchangers for condensing appliances for GRI and DOE. Based on this research, a set of guidelines was developed for the design of condensing heat exchangers. The guidelines consist of minimizing condensation in noncondensing regions of heat exchangers, reducing the corrosiveness of flue-gas condensate and using materials having a high corrosion resistance to flue-gas condensate in the condensing region (Stickford et al. 1987). European experience with condensing appliances has also shown that in addition to metal corrosion, problems could occur in rubber seals and in flue pipes (Kobussen et al. 1987). Corrosion due to condensation of combustion gases limits the thermal efficiency of a fuel-fired water heater with a standard flue pipe and vent system to 84%. Using corrosion resistant heat exchangers or side-wall venting, or lining the vent/masonry systems with corrosion resistant material, can extend the thermal efficiency limit beyond 84%.

Condensing gas appliances can be of two types: fully-condensing or near-condensing. Fully-condensing appliances will have flue gas temperatures less than the dew point (130°F to 140°F) of the flue products. Condensation is expected in both the heat exchanger and the vent system. Near-condensing appliances will have flue gas temperatures greater than the dewpoint of the flue gas. Condensation is expected in the vent system but not in the heat exchangers. The thermal efficiency of fully condensing water heaters can be as high as 99%; for near condensing water heaters, it is generally between 84% and 90%.

Several manufacturers offer near-condensing water heaters and a few offer fully-condensing types. A large-scale field test, sponsored by GRI, compared the performance characteristics of condensing with conventional non-condensing commercial water heaters (Demetri and Walters 1987). The conclusions from the field test were: 1) a detailed inspection of the nine prototype units after 2 years of field operation uncovered no serious concerns regarding reliability or durability; and 2) the overall results confirmed the technical feasibility of the condensing design and that it provided a substantial efficiency improvement over conventional equipment.

Although the field test showed no corrosion in the heat exchangers after 2 years of field operation, Lennox Industries recently noted, for certain regions of the country, a high incidence of problems with pulse heat exchangers in their condensing pulse combustion warm-air furnaces (ACHRN 1997). The secondary heat exchangers (primarily used to extract latent heat) had very high sulfur concentrations because of the high sulfur content in the supply fuel. Similar limitations may exist in gas-fired condensing water heaters, as well.

There are also some limitations with respect to the servicing and maintenance infrastructure in retrofit situations. To install a condensing flue gas water heater, the vent systems have to be replaced or modified to prevent corrosion or damage from flue-gas condensate. When two or more gas appliances are vented through the same flue, replacing the standard gas water heater with a condensing gas water heater could orphan a standard gas furnace. Essentially, the flue becomes oversized for the remaining appliance.

DOE believes that condensing water heaters are not feasible in all building situations, such as certain older homes and multi-family dwellings, where common flues are prevalent. On a national basis, this design option would require vent modifications (including relining of masonry chimneys) in 75% of the installations (Paul et al. 1991). Although DOE understands that a new flue can always be installed at some cost, it doesn't believe the Act applies to major renovations of homes and multi-family dwellings for new venting systems. Additionally, because more than 40% of all residential water heaters are sold through retail outlets, DOE is concerned that untrained homeowners or others may install condensing water heaters in a vent not designed for that equipment. Therefore, DOE will not consider this design option for the engineering analysis.

Condensing Pulse Combustion

Pulse combustion burners are another condensing technology. Pulse combustion burners operate on self-sustaining resonating pressure waves that alternately rarefy the combustion chamber (drawing a fresh fuel/air mixture into the chamber) and pressurize it (causing ignition by compression of the mixture to its flash point). This process is initiated by a blower supplying an initial fuel and air mixture to the combustion chamber. The mixture is ignited with a spark. Once resonance is produced, the process becomes self-sustaining (Vishwanath 1987). Pulse frequencies are on the order of 100 cycles per second. Pulse combustion systems feature high heat transfer rates, are capable of self-venting, and can draw outside air for combustion even when installed inside. The emissions from pulse combustion burners are 50% to 66% lower than those of a conventional burner (Vishwanath 1987). Because the pulse combustion process is highly efficient, the burners are generally used with condensing appliances. American Gas Association Laboratories (AGA Labs) built several prototypes as part of a study of pulse combustion residential water heaters (Thrasher 1986). They reported that the prototype models had a recovery efficiency of more than 90%.

This technology has not been developed for oil-fired equipment. Also, as noted in the condensing option discussion, Lennox Industries has experienced problems with pulse heat exchangers in their condensing pulse combustion warm-air furnaces. The primary considerations in using this design option is the likely condensation of flue gases and the relining or replacement of vent systems to prevent corrosion. DOE is not including this design option for the reasons given above.

Advanced Forms of Insulation

Alternate ways of reducing the jacket losses without increasing the diameter of the water heater include the use of advanced insulation materials or the use of vacuum tanks. Some of the advanced materials or methods of insulation considered here involve the use of vacuum, inert gases, air, or partial vacuums.

- Vacuum Insulation. A "hard" vacuum between internal reflective surfaces is a very good insulator. It has been used for years in Thermos bottles and Dewar tanks for cryogenic applications. Durability and the difficulty of maintaining the seal over the life of the water heater are some problems with this technology that have to be resolved.

- Gas-Filled Panels. Gas-filled panels (GFPs) are thermal insulating devices that retain a high concentration of a low-conductivity gas, at atmospheric pressure, within a multi layer infrared reflective baffle. The thermal performance of the panels depends on the type of gas fill and the baffle configuration. Calorimetric measurements have shown total resistance levels of about R-12.6 for a 1-inch thick krypton panel, R-25.7 for a 2-inch krypton panel, and R-18.4 for a 1-inch xenon panel. GFPs are flexible, self-supporting, and can be made in a variety of shapes and sizes to thoroughly fill most types of cavities. Reliability and durability of these panels over the life of the water heater has not been demonstrated.

- Aerogel Insulation. An example of advanced insulation materials is silica aerogel, which is composed of 96% air and the remaining 4% of a wispy matrix of silica (silicon dioxide). Aerogels are more efficient and weigh less than the polyurethane foam that is currently used in most water heaters. The R-value of the aerogel at atmospheric pressure is comparable to that of the polyurethane foam, but when 90% of the air is evacuated from a plastic-sealed aerogel packet, its resistance nearly triples. Another advantage of the aerogel insulation over foam insulation is avoiding the use of chlorofluorocarbons to blow the polyurethane foam into the heater jacket. New manufacturing processes have been developed that can produce flexible blankets or clamshell forms of this material. The aerogel material is vulnerable to shock and vibration, however, and material handling becomes an issue. Because it is hygroscopic, it also requires a thorough sealing of the cavity between the water heater tank and the outside cover.

- Evacuated Panels. In addition to aerogels, other materials with a lightweight open structure can create very good insulators at “soft” or low vacuums. The materials can be enclosed with metals or plastic. One company manufactures evacuated panels for refrigerators, using hermetically sealed stainless steel skins to surround a layer of special high-density rigid fiberglass. A vacuum (10^{-3} torr[1]) is drawn in this panel before sealing, and the rigid fiberglass keeps the vacuum from compressing the panel. This technology has not been demonstrated for curved surface applications, such as water heater tanks.

GAMA recommends elimination of advanced insulation materials because it would require the industry to completely restructure their production lines to accommodate a radically different way of insulating water heaters. GAMA claimed that manufacturers have not established methods to manufacture water heaters with these types of materials [GAMA, No. 5 at 6]. DOE agrees with GAMA on the issue of manufacturability. The Department is aware that one manufacturer attempted to use advanced insulation panels on refrigerators and manufacturability problems forced it to abandon the concept. Additional manufacturing development for water heater applications with adequate life testing for reliability and durability is necessary to demonstrate the practicality of these products.

U-Tube Flue

One comment on the 1994 NOPR mentioned an old water heater design that used an inverted U-shaped flue within the tank of the water heater (Larry Weingarten, Elemental Enterprises, commenter No. 496 at page 2 to the 1994 NOPR - EE-RM-94-230). This design could increase the recovery efficiency and would reduce standby losses. No working prototypes are currently available and DOE believes that this design would not meet modern safety standards, because of possible flue-gas condensation in the U-tube. Lack of working prototypes precludes from testing the option further and validating the applicability or usefulness of this particular design option.

Thermophotovoltaic and Thermoelectronic Generators

A thermophotovoltaic water heater uses a special light-emitting burner coupled with silicon photovoltaic cells that generate auxiliary power to run a fan, operate the electronic ignition and controls, and charge a battery. This avoids the requirement of auxiliary electrical supply, while offering the efficiency advantages of electronic ignition and forced-draft combustion. DOE has funded the development of prototypes of this design option in the past, but there has been no recent activity. This technology has not been demonstrated for widespread applications, such as in water heaters.

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[1]A torr is a unit of measure for vacuum levels and 1 torr equals 133 Pascals.

Another method of generating electricity at the water heater is based on thermocouple technology. Thermoelectric generators are available, but none have been used in water heaters. Furthermore, DOE understands this option and the thermophotovoltaic generator option need further development for common day-to-day applications before prototypes for water heaters can be developed and tested.

Reduced Burner Size (Slow Recovery)

Reducing burner size while keeping flue baffle and tank geometry the same will increase the ratio of heat transfer surface area per Btu of input, thereby increasing the recovery efficiency. The lower input means that recovery would be slower than with conventional burners. The first hour rating would probably be reduced, as well, although some of this first hour rating reduction could possibly be offset by changing the dip tube design, which helps to stratify the water in the tank and thereby reduce mixing. Slower recovery also implies reduced product utility by the consumer and hence will not meet one of the key screening criteria.

GAMA believes that slow recovery is another name for derating [GAMA, No. 5 at 6]. By derating, the water heater is not able to provide as much hot water. This is particularly an issue as far as large families are concerned or where large quantities of hot water are used. Therefore, DOE is eliminating this design option from further consideration because of the adverse impact on product utility.

Heat Pump Water Heater Options

Because the vast majority of electric water heaters use resistance elements to heat the water, there are few available options for substantially improving the EF. Perhaps the greatest EF improvement can be achieved by using a heat pump, rather than resistance elements, to heat the water. A heat pump water heater can easily double the EF, compared to a resistance type.

There are two types of heat pump water heaters: add-on and integral. An add-on heat pump is a separately manufactured unit designed to be added to an existing electric storage-type water heater. A small pump circulates water from the tank through the heat pump. A special class of add-on heat pump is a "return-air" heat pump, which locates the evaporator in the return air stream of the house heating, ventilating, and air-conditioning (HVAC) system.

The second type of heat pump water heater is an integral heat pump. In an integral heat pump, the heat exchanger (condenser) is built into the storage tank. This eliminates the need for a circulation pump and increases efficiency.

Although a small number of heat pump water heaters are available for sale, DOE believes that the service and installation industry is not prepared for the volume of business. Plumbers with the expertise required for installation and service of heat pump water heaters are rare. Existing HVAC technicians would not be able, nor perhaps willing, to handle large volumes of heat pump water heater installations. Also, in retrofit situations, installation of heat pump water heaters in tight enclosures is impractical.

Southern Company believes that heat pump water heaters should be eliminated as a design option because of product reliability issues and an inadequate infrastructure [Southern Company, No. 12 at 2]. In addition to these comments, several similar comments regarding the heat pump water heaters were made to the 1994 NOPR. Additional issues raised by commentors included large financial burdens on the consumer, promoting fuel switching to fossil fuel, and reduced product utility due to slow recovery rates.

DOE agrees with the commentors that there is a lack of infrastructure to adequately install and service the product. Hence, DOE will not consider this design option in the engineering analysis.

Timer Controlled

This design option limits the time of day when the elements of an electric storage-type water heater may be energized. This is most often used as part of an electric utility demand-side management program for load shifting ("demand avoidance strategy"). Field tests show a few percent energy savings, because the water in the tank remains at a reduced temperature for part of the day. However, the actual energy savings will depend on the end-use profile, lifestyle of the consumer, and a basic desire to save energy.

GAMA claims that timer controls are used as a demand avoidance device to allow consumers to use lower priced electricity [GAMA, No. 5 at 6-7]. This design does not improve efficiency because it only shifts the electric consumption from on-peak to off-peak times. Therefore, DOE will not include this in its analysis.

System Application Options

The following three techniques are applicable to the water heating system rather than to individual water heaters. Therefore, DOE does not consider these add-ons as design options and hence, not relevant for the present screening considerations.

- Solar Pre-Heat. This and the following two techniques may be relevant on a site-specific basis, and are applied at a system level as opposed to an equipment level. Individual water heater manufacturers do not control their use. This technique uses solar collectors as pre-heaters for a standard electric storage-type water heater. Many designs are currently available, with a wide range of installed costs.

- Drain Water Heat Recovery System. This technique uses a heat exchanger to recover waste heat from the drain. In effect, this becomes a pre-heater for a standard electric storage type water heater, but could be used with fossil-fired water heaters, as well. A few designs are currently available. A presentation at the recent American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Summer Meeting held in Boston in July 1997 reviewed this option for pre-heating the shower water in a house. But recent water conservation measures, such as low-flow showerheads, may lead to fewer benefits than previously thought.

- Tempering Tank. A tempering tank is an un-insulated storage tank plumbed in the water line before the water heater. When installed in a conditioned or semi-conditioned space, it may raise the inlet water temperature to the ambient temperature.

GAMA states that solar pre-heat, drain water heat recovery systems, and tempering tanks are installation options independent of the water heater design [GAMA, No. 5 at 7]. DOE agrees with GAMA and considers these as system installation features that are beyond the control of water heater manufacturers.

Sediment Removal Features

Several manufacturers offer models with dip-tubes designed to create turbulent water flow that prevents or limits the buildup of sediment on the bottom of the tank. This may reduce the degradation of efficiency and prolong the life of the water heater. This design feature relates more to equipment reliability than efficiency improvement.

GAMA claims that sediment removal features are not a design option applicable to meeting a minimum efficiency specification [GAMA, No. 5 at 7]. DOE agrees with the comment and believes this only preserves as-designed efficiency over time but does not increase energy efficiency of the water heater. Therefore, DOE will not consider this design option for the engineering analysis because the current test procedure was only intended to measure the efficiency of new water heaters.

Two-Phase Thermosiphon (TPTS) Design

This is a heat-pipe mechanism to transfer heat from the burner to the storage tank. The TPTS is a closed loop device consisting of an evaporator in which the working fluid (water) is heated, percolating liquid and vapor into the condenser where heat is transferred into the water storage tank (Topping 1988). At the condenser, the vaporized working fluid is condensed and drains back through a separate restricted tube to the evaporator, where it is reheated. The restriction prevents the heated vapor and liquid from flowing to the condenser through the return path. During off-cycle, there is very little heat transfer through the TPTS system. This reduces standby losses to levels similar to those of electric water heaters.

GAMA believes the TPTS system would cause a drastic redesign of all gas water heaters with little increase in efficiency [GAMA, No. 5 at 6]. DOE understands that working prototypes of the heat exchanger design have been developed and delivered to Rheem Corporation for detailed performance and life testing. However, DOE is aware that some designs of heat pipes used in furnace applications posed safety problems due to contamination of the working fluid. DOE concludes that large scale production of these devices has not been satisfactorily demonstrated. Therefore, DOE will not include this design option in the engineering analysis on the basis of practicality.

RECOMMENDATIONS

Based on the above discussion, the design options that will be used in the engineering analysis are listed in Table 1, and those that have been eliminated from further consideration are listed in Table 2.

TABLE 1. Design Options to be Used in the Engineering Analysis

Design Options - Description	Gas	Electric	Oil
Heat Traps	X	X	X
Plastic Tank	X(1)	X	
Increased Jacket Insulation	X	X	X
Insulating the Tank Bottom (Electric Only)		X	
Improved Flue Baffle/Forced Draft	X		X
Increased Heat Exchanger Surface Area	X		X
Flue Damper (Electromechanical)	X		
Side-Arm Heater	X		
Electronic (or Interrupted) Ignition	X		X
Air-Atomized Burner (Oil-Fired Only)			X
(1) used in conjunction with the side-arm heater option			

TABLE 2. Design Options Eliminated from Further Consideration

Design Options -- Description	Criteria for Elimination
Flue Damper (Buoyancy Operated)	Safety issues and lack of long-term use data
Submerged Combustion	Conflict with health and safety codes
Directly Fired	Conflict with health and safety codes
Condensing Option	Venting Application Restrictions
Condensing Pulse Combustion	Venting Application Restrictions
Advanced Forms of Insulation	Fails the practicability to manufacture criterion
U-Tube Flue	Lack of working prototypes and conflict with safety codes
Thermophotovoltaic and Thermoelectronic Generators	Lack of application to water heaters
Reduced Burner Size (Slow Recovery)	Adverse impact on product utility
Heat Pump Water Heater Options	Lack of service and installation infrastructure and product utility concerns
Timer Controlled	Not an efficiency improvement option
System Application Options	System installation feature
Sediment Removal Features	Not an efficiency improvement option
Two-Phase Thermosiphon (TPTS) Design	Fails the practicability to manufacture

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